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Medium-Sized Mammals around a Radioactive Liquid Waste Lagoon at Los Alamos National Laboratory: Uptake of Contaminants and Evaluation of Radio-Frequency Identification Technology

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ABSTRACT

Use of a radioactive liquid waste lagoon by medium-sized mammals and levels of tritium, other selected radionuclides, and metals in biological tissues of the animals were documented at Technical Area 53 (TA-53) of Los Alamos National Laboratory during 1997 and 1998. Rock squirrel (*Spermophilus variegatus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and bobcat (*Lynx rufus*) were captured at TA-53 and at a control site on the Santa Fe National Forest. Captured animals were anesthetized and marked with radio-frequency identification (RFID) tags and/or ear tags. We collected urine and hair samples for tritium and metals (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and thallium) analyses, respectively. In addition, muscle and bone samples from two rock squirrels collected from each of TA-53, perimeter, and regional background sites were tested for tritium, ^{137}Cs, ^{90}Sr, ^{238}Pu, ^{239,240}Pu, ^{241}Am, and total uranium. Animals at TA-53 were monitored entering and leaving the lagoon area using a RFID monitor to read identification numbers from the RFID tags of marked animals and a separate camera system to photograph all animals passing through the monitor. Cottontail rabbit (*Sylvilagus* spp.), rock squirrel, and raccoon were the species most frequently photographed going through the RFID monitor. Less than half of all marked animals in the lagoon area were detected using the lagoon. Male and female rock squirrels from the lagoon area had significantly higher tritium concentrations compared to rock squirrels from the control area. Metals tested were not significantly higher in rock squirrels from TA-53, although there was a trend toward increased levels of lead in some individuals at TA-53. Muscle and bone samples from squirrels in the lagoon area appeared to have higher levels of tritium, total uranium, and ^{137}Cs than samples collected from perimeter and background locations. However, the committed effective dose equivalent estimated from the potential human consumption of the muscle and bone tissue from these rock squirrels did not suggest any human health risk. Indirect routes of tritium uptake, possibly through consumption of vegetation, are important for animals in the lagoon area.

INTRODUCTION

Radioactive and nonradioactive contamination of soil, vegetation, invertebrates, and small mammals has been confirmed in areas on Los Alamos National Laboratory (LANL) (Fresquez et al. 1996*a*, *b*, EAREG 1996, Biggs et al. 1995, Fresquez et al. 1995*a*, *b*, *c*, Brooks 1989). Medium-sized mammals such as raccoons (*Procyon lotor*), bobcats (*Lynx rufus*), striped skunks (*Mephitis mephitis*), gray foxes (*Urocyon cinereoargenteus*), squirrels, (*Spermophilus* spp., *Sciurus* spp.), and rabbits (*Sylvilagus* spp.) may be exposed to heavy metals, organic compounds, and low-level radionuclides at LANL (Brooks 1989). Medium-sized mammals are important ecosystem components. They are also used as ceremonial animals by Native Americans, are an economic resource for trappers, and may be used for food.

While LANL annually conducts extensive monitoring of radioactive and nonradioactive contaminant levels in groundwater, surface water, soils, sediments, the atmosphere, and foodstuffs (EAREG 1996), little information is available on the occurrence of contaminants in natural vegetation (Fresquez et al. 1996*b*, Fresquez 1995*c*, Wenzel et al. 1987) and herbivores (Biggs et al. 1995, Fresquez et al. 1995*a*). To date no data are available on contaminant uptake in medium-sized mammals. Accumulation of contaminants in individuals and transfer along food chains are among the more important processes that must be evaluated to predict contaminant effects on the environment (Petron 1993, Martin and Coughtrey 1982, Ketchum et al. 1975). Knowledge of animal use of potential release sites of contaminants (PRSs), contaminant levels in animals, and subsequent transport within the environment can be used to evaluate risks of contaminants to the environment and provides data to examine remediation options.

Because of their relatively low densities and frequently nocturnal habits, medium-sized mammals are difficult to study. Previously, the only technique to document movements of individual animals was radiotelemetry. We evaluated an application of radio-frequency identification (RFID) technology. RFID technology allows a very small (23-mm by 3.2-mm) glass-encapsulated “tag” to be subcutaneously implanted in animals with a syringe and needle. Tags last for the lifetime of the animal. The RFID system consisted of a monitor and automatic data recorder that detected and recorded the individual identification numbers from the tags of marked animals as they passed through the monitor portal.

We fenced a PRS so that the RFID monitor provided the only ready access to the site. As a marked animal walked through the RFID monitor, the RFID system recorded the identification number of the animal from the tag, along with the date and the time. This technology allowed us to remotely record the amount of time marked animals spent at a PRS. In addition, we operated a separate remote camera system marketed by Trailmaster® to photograph marked and unmarked animals passing through the monitor.

The objectives of this project were

- Evaluate the RFID system as a technique to allow LANL to efficiently document the amount of time spent at a PRS by individual animals.

- Determine whether medium-sized mammals at LANL exhibit elevated levels of metals or select radionuclides.
- Collect data on the relationship between the amount of time spent at a PRS and levels of contamination.

STUDY AREA

The monitor and fencing were assembled around a radioactive liquid waste treatment lagoon at the Los Alamos Neutron Science Center (LANSCE) at Technical Area 53 (TA-53). LANSCE is a national user facility at LANL that provides intense sources of pulsed spallation neutrons for neutron research and applications. Operation of the linear accelerator and associated cooling systems produces radioactively contaminated liquid wastes. During the study period all potentially radioactive liquid wastes were collected and delivered to holding tanks. The waste was retained in the holding tanks until short half-life constituents decayed. Tank contents were then pumped to a radioactive liquid waste treatment lagoon. LANSCE is located on a mesa in a pinyon-juniper woodland. Our control site was in Guaje and Rendija Canyons on Santa Fe National Forest lands, approximately 5 km north of the lagoon site (Figure 1).

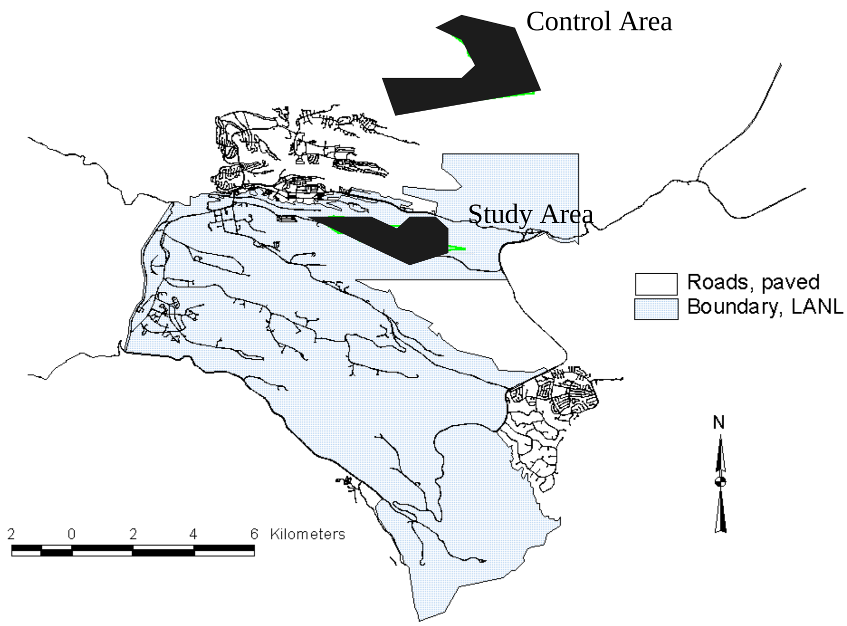

Figure 1. Location of control and study areas at Los Alamos National Laboratory

METHODS

A fence was completed around the TA-53 radioactive liquid waste lagoon in March and April 1997. Safety barrier fencing was attached to an already existing hogwire fence around three sides of the lagoon and was strung across the fourth side using t-posts. Three-foot-tall chicken wire was placed along the bottom of the fencing and was buried approximately two inches in the soil. In 1998, this fencing was improved by burying the chicken wire six inches in the soil and placing an electrically charged livestock wire around the top of the fence.

Medium-sized mammals (rock squirrels, raccoons, striped skunk, and bobcat) were captured at TA-53 and the control site using cage traps during March through August in 1997 and March through July in 1998. Animals were captured at TA-53 in two different areas (Figure 2): within 400 m of the lagoon (at the lagoon) and more than 400 m from the lagoon (away from the lagoon). Captured animals were taken to an animal holding facility. There, we anesthetized the animals, took measurements, and collected 2 to 4 g of hair. We inserted RFID tags subcutaneously between the shoulder blades of animals captured at TA-53. Animals were retained in the holding facility overnight in metabolic cages, and urine was collected in trays beneath the cages. Animals were released at their capture site the following day. Water samples were collected once a month from the lagoon during April-June of 1998.

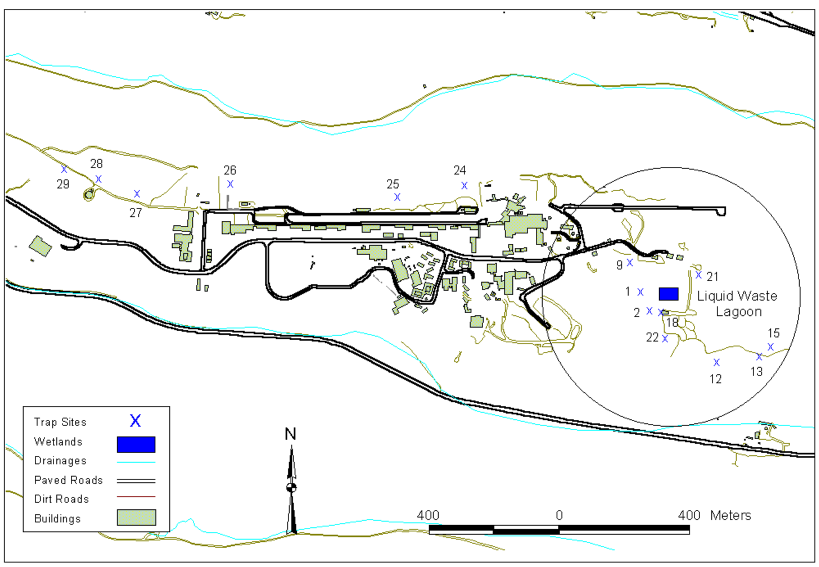

Figure 2. Locations of traps at TA-53. The circle is a 400-m buffer around the liquid waste lagoon. Animals captured inside the circle are considered to be at the lagoon. Animals captured outside the circle are considered to be away from the lagoon.

Urine and water samples were submitted to the Chemical Science and Technology Division (CST) at LANL to determine the concentration of tritium using distillation and liquid scintillation counting. The minimum detectable activity with this technique is approximately 450 pCi/L (CST 1999). Hair samples were submitted to CST to determine concentrations of aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), and thallium (Tl). Hair samples were not washed prior to analysis. Inductively coupled plasma emission spectrometry was used to estimate concentrations of Ag, Al, Ba, Be, Cd, Cr, Cu, and Ni. Inductively coupled plasma mass spectrometry was used to estimate concentrations of Hg (in 1998 only), Pb, Sb, and Tl. Electrothermal vaporization atomic absorption spectroscopy was used to estimate concentrations of As and Se. Cold vapor atomic absorption spectroscopy was used to estimate concentrations of Hg in 1997 only. We assumed that samples with nondetectable results had metal concentrations equal to ½ of the detection limit.

For rock squirrels, we analyzed both tritium and metals data using Kruskal-Wallis tests for differences among years, sexes, and locations. No other species were captured in sufficient numbers to test for differences. The tritium data tended to be highly non-normal. Therefore, we reported median values rather than mean values. For rock squirrels captured in the lagoon area, we used Spearman's rank correlation to test for a correlation between tritium concentrations in rock squirrel urine and distance the animal was captured from the lagoon (Conover 1980). Spearman's rank correlation was also used to examine the distance male and female rock squirrels moved between trapping occasions (Conover 1980). A Mann-Whitney U test was used to determine if there were significant differences in the levels of tritium between animals that were documented visiting the lagoon and those that were not.

The RFID monitor was placed as an opening in the fence through which animals could access the TA-53 lagoon (Figure 3). Two Trailmaster® (TM®) detectors and cameras (referred to as top and bottom) were placed to photograph any animal passing through the monitor (Figure 3). We operated the monitor and cameras continuously during May 1997 to October 1998 to document use of the lagoon area by marked and unmarked animals. We compared results from the two detection methods.

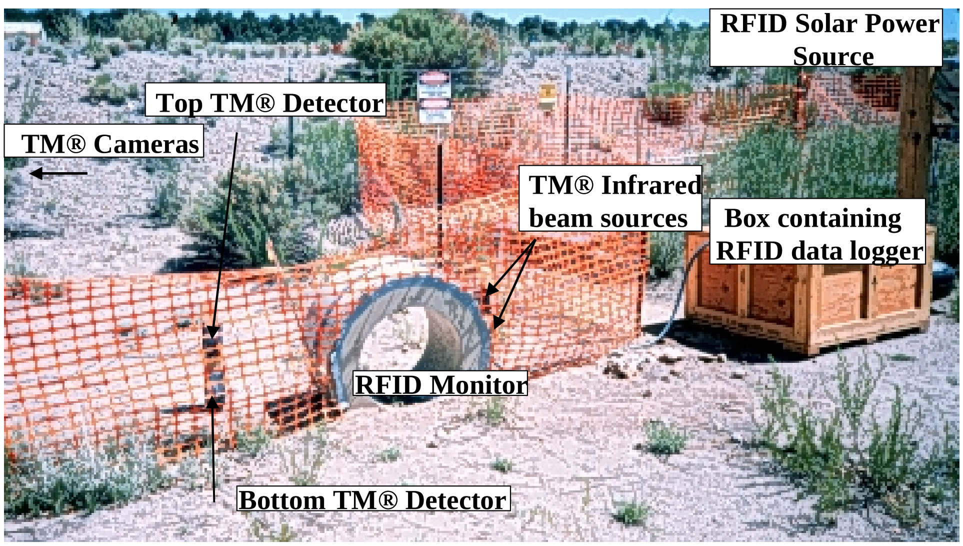

Figure 3. Picture of the RFID Monitor and Trailmaster® Camera System set up at the entrance to the TA-53 lagoon.

To estimate potential human health risks from ingestion of the animals that reside at TA-53, radionuclide levels in bone and muscle tissue of rock squirrels collected as road kills or collected from other sources were compared to two rock squirrels collected from the lagoon area. Results from these analyses were used to estimate the potential human dose resulting from consumption of rock squirrels resident at TA-53. Two squirrels were collected near the TA-53 lagoons at LANL, two squirrels were collected from the perimeter of LANL (Los Alamos townsite and Rendija Canyon), and two squirrels were collected from background locations in Española. In most situations, the squirrels were placed in a clean plastic bag and transported back to the laboratory in a locked ice chest cooled to 4°C. The skin was removed from muscle and bone tissue, and approximately 10 grams of wet subsample from each material was placed into a ^{3}H distillation unit and heated to collect distillate (water) for ^{3}H analysis. The remaining muscle and bone sample(s) were then thoroughly rinsed with tap water and towel dried, placed into tared 2-L beakers, and weighed (the squirrels collected from the TA-53 lagoon area were composited). The beaker contents were oven dried at 75°C for 120 h, weighed, and slowly ashed incrementally to 500°C for 120 h. The sample ash was weighed, pulverized, and homogenized before it was submitted with the distillate samples to CST for analysis of tritium, ^{137}Cs, ^{90}Sr, ^{238}Pu, $^{239,240}Pu$, ^{241}Am, and total uranium. All methods of radiochemical analysis have been described previously (Fresquez et al. 1994). Results are reported on a pCi L^{-1} (tissue moisture) basis for tritium and on an oven dry weight basis (g dry) for the remaining elements. Moisture conversion factors (ash to dry) for muscle and bone in squirrels can be found in Fresquez and Ferenbaugh (1998).

The committed effective dose equivalent (CEDE) to humans was calculated following procedures recommended by the Department of Energy (USDOE 1991) and the Nuclear Regulatory Commission (NRC 1977). The general process for calculating radiological dose from ingestion of muscle and bone was as follows. First, following conversion from dry to wet weight concentrations (Fresquez and Ferenbaugh 1998), the wet concentration of radionuclides in the meat or bone was multiplied by a dose conversion factor that tells how much radiological dose occurs per unit of food ingested (USDOE 1988). Where different dose conversion factors were provided for a radionuclide, the most conservative (highest) factor was employed. The dose calculated is the 50-year CEDE and is reported on a per lb of meat or bone basis so that individuals may calculate their own doses based on their knowledge of their actual consumption rates. Finally, the CEDE was multiplied by 5×10^{-7} excess cancer fatalities per person-mrem (NCRP 1993) to calculate the risk of excess cancer fatalities (RECF) from whole-body radiation from the consumption of muscle and bone. There is considerable amount of controversy over RECF estimates within the health community. Health effects from radiation exposure, including cancer, have been observed in humans only at doses in excess of 10 rem (10,000 mrem) delivered at high dose rates (HPS 1996). Therefore, risk estimates provided in this paper are a conservative and qualitative guide only.

RESULTS

Animal Capture

Between 18 March 1997 and 30 August 1997 we captured 22 animals a total of 52 times. Animals captured included 19 rock squirrels, two raccoons, and one striped skunk. Based on the initial capture location, we captured 12 animals at the lagoon area, five away from the lagoon, and five in the control area. Eight rock squirrels, one raccoon, and one striped skunk from the lagoon area were implanted with RFID tags. Four rock squirrels and one raccoon from away from the lagoon were implanted with RFID tags. One rock squirrel was captured both away from the lagoon and at the lagoon area. This rock squirrel traveled 961 m between traps in six days. One grey fox was captured during preliminary trapping at TA-53 in December 1996. The hair sample from this fox is included in our analyses.

Between 4 March 1998 and 23 July 1998 we captured 35 animals a total of 53 times. Animals captured included 32 rock squirrels, one raccoon, one striped skunk, and one bobcat. Six rock squirrels and one striped skunk initially captured in 1997 were recaptured in 1998. In addition, one raccoon captured in 1997 was detected going through the RFID monitor in 1998. Therefore, in 1998 we had 16 rock squirrels, one raccoon, and one striped skunk from the lagoon area either implanted with RFID tags or retaining RFID tags from 1997. Three rock squirrels, one raccoon, and one bobcat from away from the lagoon either were implanted with RFID tags or retained RFID tags from 1997. Thirteen rock squirrels were captured in Guaje and Rendija Canyons on Santa Fe National Forest land and sampled. Contaminant levels in these animals were used for comparison to levels in animals captured at TA-53. However, seven hair samples from the control area animals were not submitted for metals analysis in 1998.

We calculated average distance moved between trap sites for rock squirrels captured at TA-53 within years and between years, and tested whether sex, year, or time elapsed since last capture affected distance moved. An analysis of variance found no significant difference between sexes ($F = 0.849$, $n = 41$, $P = 0.363$) or years ($F = 2.495$, $n = 41$, $P = 0.123$) in the distance moved by rock squirrels between trapping occasions within years. Therefore sexes and years were pooled. Fourteen rock squirrels (8 M, 6 F) were recaptured on 41 occasions (20 M recaptures, 21 F recaptures) within years. The average distance moved between traps was 114 m (SD = 174), with a range of 0 to 961 m. We also calculated the average distance moved between the last capture in 1997 and the first capture in 1998 for six rock squirrels that were captured in both years. The average distance moved between traps between years was 192 m (SD = 195) with a range of 0 to 516 m. There was no correlation between the time since last capture and the distance moved between trap sites within years ($r = -0.121$, $n = 41$, $P = 0.452$).

Effectiveness of the RFID Monitor and Trailmaster® Systems

We operated the RFID monitor and the Trailmaster® camera systems beginning on 13 May 1997 through the end of the study, 30 September 1998. However, the Trailmasters® were ineffective during winter because of infrequent maintenance and triggering of the detectors by snow. In addition, rock squirrels are inactive in the winter, and thus not available for detection. Therefore only the period between 15 May and 15 September was evaluated for each year. The number of days the top and bottom Trailmaster® systems were operational during that period is given in Table 1. Failure was defined as the Trailmaster® system not taking pictures of animals passing through the monitor. Reasons for failure included (1) some object (such as waving grass or falling snow) triggered the Trailmaster® repeatedly, so that the number of observations exceeded the capacity of the detector and/or caused the camera to run out of film; (2) the camera ran out of film for other reasons; (3) Trailmaster® batteries went dead; and (4) camera batteries went dead. The Trailmaster® detectors were set on their most sensitive setting to detect smaller mammals, such as rock squirrels. We checked the RFID monitor and Trailmaster® systems once a week. This schedule was insufficient to prevent the Trailmaster® systems from failing on a substantial number of days.

Table 1. Number of days the top and bottom Trailmaster® camera systems were known to be operational during the evaluation periods of 15 May through 15 September in 1997 and 1998.

Year	No. of days available for operations during the evaluation period	Number of days top Trailmaster® was operational	Number of days bottom Trailmaster® was operational
1997	123	84 (68%)	86 (70%)
1998	123	112 (91%)	90 (73%)

To evaluate the effectiveness of the Trailmaster® camera systems, we examined the number of passages of marked animals detected with the RFID monitor that were also detected with the Trailmaster® system. A passage indicates that an individual animal traveled one way through the RFID monitor (either into or out of the lagoon area). During the 1997 evaluation period, five marked individuals were detected with the RFID monitor (four rock squirrels, one raccoon) making 10 passages. Of these 10 passages, six (60%) were not detected by the Trailmaster® system (either Trailmaster® detectors were not operational or the animal did not break the infrared beam), three (30%) were detected and photographed, and one (10%) was detected but not photographed. It is possible that animals passed partway through the RFID monitor and were detected by it but did not trigger the Trailmaster® detectors. In 1998, four marked individuals (two rock squirrels, one raccoon, and one bobcat) made a total of 19 passages through the RFID detector. Of these passages, seven (37%) were not detected by the Trailmaster® system, six (32%) were detected but not photographed, three (16%) were detected but had no animal in the picture, indicating that the animal passed through the frame area of the cameras too fast to be photographed, and three (16%) were detected and photographed.

The RFID monitor only suffered one period of failure, although it took approximately six weeks to detect, diagnose, and fix the problem. The data logger for the RFID monitor indicates when it is scanning. We began noticing that on some days the logger indicated it was not scanning, and the problem got progressively worse over time. After attempting to fix and then replace the data logger, we finally determined that the battery attached to the solar panel had failed. The data logger was operating during the day using power from the solar panel, but would turn off at night and not come back on. An unknown number of days when detections with the RFID monitor were not possible were lost to this equipment malfunction.

<u>Animals Detected at the Lagoon</u>

Figure 4 shows the number of passages of all animals (marked and unmarked) photographed going either into or out of the monitor during the evaluation periods in 1997 and 1998. Sometimes there were multiple images of an animal taken within a few minutes. We assumed that this occurred because one individual triggered the Trailmaster® system several times in the process of moving around the monitor area, and counted these images as one passage. Based on results comparing photographs of marked animals to RFID detections of marked animals, we estimate that photographic counts represent less than 50% of the actual passages made by animals into or out of the lagoon, possibly substantially less.

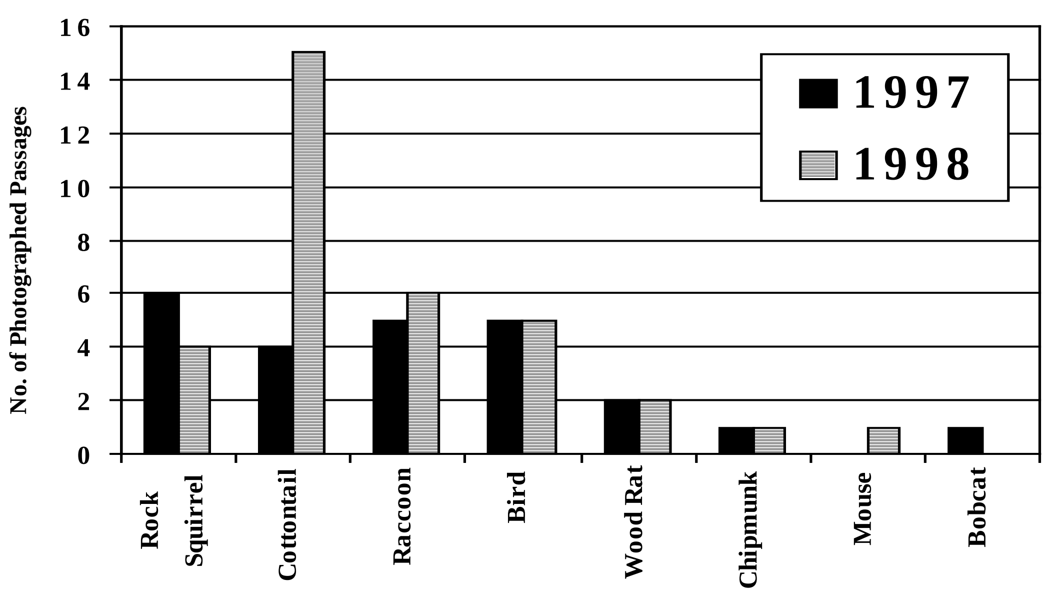

Figure 4. Counts of passages by different species through the RFID monitor during 15 May-15 September, 1997 and 1998.

During our 1997 evaluation period, five marked individuals were detected with the RFID monitor (four rock squirrels, one raccoon) making a total of 10 passages. Of the marked animals detected by the RFID monitor, four were from the lagoon area (40% of lagoon marked animals) and one was from away from the lagoon (25% of away marked animals). Four of the ten passages (40%) appeared to be paired (one individual entering and leaving the lagoon area within 24 hours). In 1998, four marked individuals (two rock squirrels, one raccoon, and one bobcat) made a total of 19 passages through the RFID detector. Three of the marked animals detected by the RFID monitor were from the lagoon area (17% of lagoon marked animals) and one (the bobcat) was from away from the lagoon (20% of away marked animals). Fourteen of the 1998 passages (74%) appeared to be paired. The large increase in the proportion of paired readings in 1998 (74%) versus 1997 (44%) suggests our fence modifications in 1998 improved our detection of animals using the lagoon.

Paired passages were used to estimate how much time animals spent in the lagoon area. In 1997 two squirrels had one pair of passages each. In 1998 one squirrel had eight pairs of passages and one bobcat had one pair of passages. The bobcat spent 16.4 minutes in the fenced lagoon area. We combined the data for 1997 and 1998 for squirrels. The rock squirrels spent an average of 26.0 minutes (SD =33.6) in the fenced lagoon area. Rock squirrels' times in the fenced lagoon area ranged from 2.5 minutes to 100.7 minutes.

<u>Radionuclide Analyses</u>

Samples of water from the lagoon in 1998 had tritium concentrations of 3.9 million pCi/L on 1 April, 14.7 million pCi/L on 4 May, and 3.2 million pCi/L on 7 June. Median values of tritium in urine from animals captured on LANL in 1997 and 1998 are presented in Table 2 and individual values are given in Appendix 1. The highest concentration recorded for tritium in urine was 1.1 million pCi/L of tritium from a raccoon captured on May 28, 1998. A raccoon was photographed entering the lagoon early in the morning (01:12) of May 25, 1998, and leaving late that night (23:46). We speculate that the raccoon with the high tritium concentration was this same individual.

Table 2. Number of animals sampled (n), median tritium concentrations (pCi/L), and range (in parentheses) in urine from animals captured in 1997 and 1998 at Technical Area 53 of Los Alamos National Laboratory.

	1997		1998	
Species	n	Tritium	n	Tritium
Raccoon	1	3150	1	1081000
Rock Squirrel	11	3520 (11010)	17	2890 (41980)
Striped Skunk	1	10	1	20

We tested for significant differences between sexes and years for rock squirrel tritium urine concentrations in the lagoon and control locations. In 1998 there was a significant difference between males and females at the lagoon area (Kruskal-Wallis test; n = 10 F, 5 M; P = 0.027). There was no significant differences between sexes at the lagoon in 1997 (n = 3 F, 4 M; P = 0.724) or at the control in 1998 (n = 4 F, 9 M; P = 0.440). Only females were captured in the control area in 1997. Within sexes, there were no significant differences between years in the lagoon area (Males: n = 4 in 1997, 5 in 1998; P = 0.086; Females: n = 3 in 1997, 10 in 1998; P = 0.176) or for females in the control area (n = 4 in 1997, 4 in 1998; P = 0.564). Based on these analyses, we pooled years, but analyzed males and females separately. An analysis of tritium concentrations in rock squirrel urine from the three different areas (at the lagoon, away from the lagoon, and control) found significant differences among the areas for both males (n = 9 at lagoon, 4 away from lagoon, and 9 at the control; P = 0.001) and females (n = 13 at lagoon, 2 away from lagoon, and 8 at the control; P = 0.001) using Kruskal-Wallis tests (Table 3). For male squirrels, animals both at the lagoon and away from the lagoon were significantly different from the control ($\alpha = 0.05$). For females, only animals at the lagoon were significantly different from the control ($\alpha = 0.05$). Plots of tritium values over time for rock squirrels from the lagoon area are presented in Figure 5.

Table 3. Median tritium concentrations (pCi/L) and range (in parentheses) in rock squirrel urine from animals captured in 1997 and 1998 in three locations: at the lagoon, away from the lagoon, and at the control area.

Sex	At Lagoon		Away from Lagoon		Control Area	
	n	Median	n	Median	n	Median
Male	9	2290 (10460)	4	3345 (8620)	9	-20 (1140)
Female	13	11200 (41670)	2	970 (1500)	8	400 (2050)

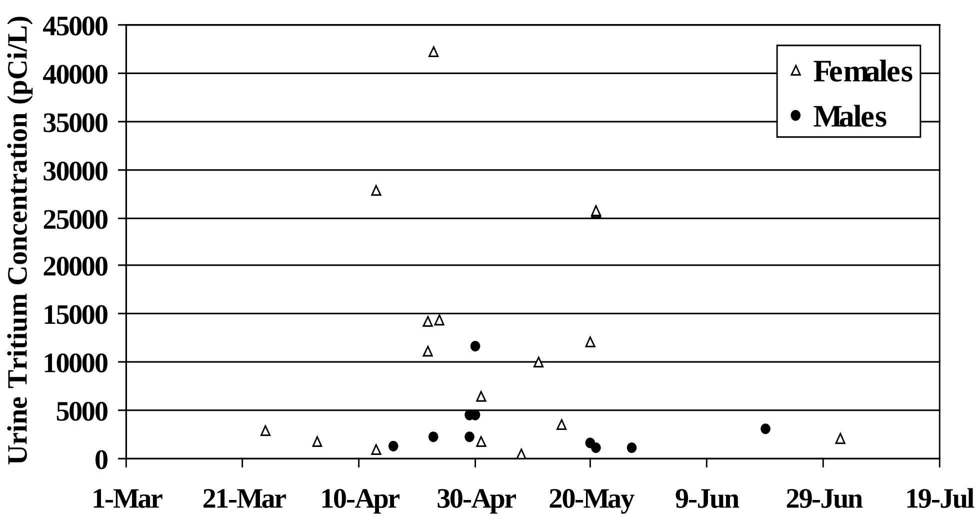

Figure 5. Graph of the urine tritium concentrations of male and female rock squirrels captured in the lagoon area by date in 1997 and 1998.

Spearman's rank correlation was used to test the relationship between distance from the lagoon and urine tritium concentrations for rock squirrels in the lagoon area. Each animal's capture location was used as an estimate of its distance from the lagoon. At the lagoon, females tended to have a negative trend between distance and urine tritium concentrations, although the correlation was not significant ($n = 13$, $r_s = -0.49$, $P = 0.098$). Males did not have a trend between distance and urine tritium levels ($n = 8$, $r_s = -0.086$, $P = 0.826$).

We also tested for a difference in urine tritium concentrations between animals that were known to have used the lagoon and animals that were not detected using the lagoon. Only one of the 14 female rock squirrels sampled at TA-53 was detected using the lagoon, so there was an insufficient sample to conduct the test. Four of 13 male rock squirrels sampled at TA-53 were detected using the lagoon. There was no significant difference in the tritium levels of males that were detected using the lagoon and males that were not (Mann-Whitney U test statistic = 10.0; n = 4, 9; P = 0.217).

During 1997 and 1998 muscle and bone samples from rock squirrels collected at TA-53, perimeter locations around LANL, and background locations at Española were submitted for radionuclide analyses. Some radionuclides, particularly tritium, ^{tot}U, and ^{137}Cs, were higher in muscle tissue of the squirrels collected from TA-53 than in muscle tissues collected from perimeter and background locations (Table 4). Bone tissue in squirrels collected from TA-53 was higher in concentrations of tritium and ^{137}Cs and especially in ^{tot}U and ^{90}Sr than background concentrations (Table 5). However, the ^{90}Sr concentration in bone tissue of squirrel was not a detectable value (the analytical result was lower than two times the counting uncertainty and therefore was not significantly different from zero) and should be viewed with caution. Total U in squirrel bone from TA-53, on the other hand, was over 600 times higher than bone tissue collected from squirrels at background locations.

The CEDE was calculated for human consumption of rock squirrels based on the data in Tables 4 and 5. All of the CEDEs were low, particularly those estimated using mean source terms for squirrel muscle (Table 6). The upper (95%) level net CEDE (mean plus two standard deviations minus background) for the consumption of one lb of squirrel muscle from TA-53 was 0.099 mrem/y. The upper (95%) level net CEDE for the consumption of one lb of squirrel bone from TA-53 was 0.47 mrem/y, and approximately 50% of the dose was a result of ^{90}Sr. The upper (95%) level net CEDE for the consumption of one lb of squirrel muscle from perimeter was –0.0003 mrem/y. The upper (95%) level net CEDE from the consumption of one lb of squirrel bone from the perimeter was 0.010 mrem/y. The worst case muscle plus bone net CEDE (0.57 mrem/y) was far below the International Commission on Radiological Protection permissible all pathway dose limit of 100 mrem/y. The RECF from the worst case muscle plus bone net CEDE (0.57 mrem/y) was 2.9E-07 (0.3 in a million) and was far below the Environmental Protection Agency upper level guideline of 10^{-4} (100 in a million).

Table 4. Radionuclides in samples of muscle of rock squirrels collected from on-site (LANL), perimeter, and regional background locations during 1997 and 1998.

Location	**^{3}H pCi/L**	**^{tot}U ng/g dry**	**^{137}Cs 10^{-3} pCi/g dry**	**^{90}Sr 10^{-3} pCi/g dry**	**^{238}Pu 10^{-5} pCi/g dry**	**$^{239, 240}Pu$ 10^{-5} pCi/g dry**	**^{241}Am 10^{-5} pCi/g dry**
LANL							
TA-53	15500 (1400)[a]	11.60 (1.20)	88.8 (15.2)	-1954.0 (4729.2)	30.8 (14.0)	3.6 (8.8)	54.8 (18.8)
Perimeter							
Los Alamos	-130 (630)	1.60 (0.40)	4.8 (7.2)	-49.2 (48.0)	-80.0 (46.0)	-6.4 (48.4)	42.8 (16.4)
Rendija Canyon	-180 (630)	2.00 (0.40)	27.6 (41.6)	-78.8 (82.0)	-77.2 (40.4)	-72.8 (57.6)	88.4 (29.2)
Mean (SD)		1.80 (0.28)	16.2 (16.1)	-64.0 (20.9)	-78.6 (2.0)	-39.6 (47.0)	65.6 (32.2)
Regional Background							
Espanola	-270 (630)	0.00 (0.40)	49.2 (74.0)	-74.8 (66.0)	-88.0 (45.6)	-10.8 (104.0)	54.4 (22.8)
Espanola	-110 (640)	0.00 (0.40)	58.8 (88.0)	-129.6 (61.2)	39.6 (14.8)	-38.0 (127.6)	70.8 (28.8)
Mean (SD)		0.00 (0.00)	54.0 (6.8)	-102.2 (38.8)	-24.2 (90.2)	-24.4 (19.2)	62.6 (11.6)

[a](±1 counting uncertainty); values are the uncertainty of the analytical results at the 65% confidence level.

Table 5. Radionuclides in samples of bone of rock squirrels collected from on-site (LANL), perimeter, and regional background locations during 1997 and 1998.

Location	^{3}H pCi/L	^{tot}U ng/g dry	^{137}Cs 10^{-3} pCi/g dry	^{90}Sr 10^{-3} pCi/g dry	^{238}Pu 10^{-5} pCi/g dry	^{239,240}Pu 10^{-5} pCi/g dry	^{241}Am 10^{-5} pCi/g dry
LANL							
TA-53	16200 (1400)[a]	2053.60 (204.00)	98.6 (17.0)	2002.6 (9292.2)	47.6 (20.4)	30.6 (20.4)	98.6 (34.0)
Perimeter							
Los Alamos	-170 (630)	3.40 (3.40)	163.2 (244.8)	608.6 (156.4)	34.0 (652.8)	-972.4 (856.8)	295.8 (136.0)
Rendija Canyon	-290 (620)	3.40 (3.40)	23.8 (34.0)	761.6 (153.0)	163.2 (44.2)	71.4 (40.8)	156.4 (64.6)
Mean (SD)		3.40 (0.00)	93.5 (98.6)	685.1 (108.2)	98.6 (91.4)	-450.5 (738.1)	226.1 (98.6)
Regional Background							
Espanola	-170 (630)	3.40 (3.40)	-17.0 (37.4)	122.4 (146.2)	680.0 (268.6)	391.0 (319.6)	397.8 (81.6)
Espanola	-210 (630)	3.40 (3.40)	34.0 (51.0)	136.0 (98.6)	30.6 (125.8)	125.8 (306.0)	136.0 (61.2)
Mean (SD)		3.40 (0.00)	8.5 (36.1)	129.2 (9.6)	355.3 (459.2)	258.4 (187.5)	266.9 (185.1)

[a](±1 counting uncertainty); values are the uncertainty of the analytical results at the 65% confidence level.

Table 6. The committed effective dose equivalent for the ingestion of squirrel tissues collected from on-site (LANL), perimeter, and regional background (RBG) locations.

Location	mrem/lb (±2SD)
Muscle:	
LANL (TA-53)	-0.0240 (0.1230)
Perimeter	-0.0009 (0.0008)
RBG	-0.0010 (0.0012)
Bone:	
LANL (TA-53)	0.1000 (0.3830)
Perimeter	0.0141 (0.0113)
RBG	0.0086 (0.0067)

Metals Analysis

Mean values of metal concentrations in hair samples for each species captured at TA-53 are presented in Table 7 and individual values are given in Appendix 2a and 2b. We tested for significant differences between sexes and years for rock squirrel hair metal concentrations at the lagoon location. Only one metal in one year was significantly different between sexes, out of 28 tests of 14 metals. However, 13 out of 28 tests between years were significant.

Based on these results, we pooled the results for males and females but analyzed years separately. We tested for significant differences in concentrations of metals in rock squirrel hair among areas (animals captured at the lagoon, animals captured away from the lagoon, and animals captured in the control area) using Kruskal-Wallis tests (Table 8). In 1997, aluminum ($P = 0.009$), beryllium ($P = 0.001$), and selenium ($P = 0.028$) differed among sites, and barium ($P = 0.089$) and arsenic ($P = 0.085$) tended to differ among sites. Kruskal-Wallis mean separation tests ($\alpha = 0.05$) indicated that aluminum levels were significantly lower at the lagoon than at the control site, that beryllium levels both at the lagoon and away from the lagoon were significantly lower than in the control area, and that selenium levels at the lagoon were significantly lower than away from the lagoon (Conover 1980). In 1998, beryllium ($P = 0.049$) differed among locations, and barium ($P = 0.085$) and lead ($P = 0.072$) tended to differ among locations. Although the overall Kruskal-Wallis test indicated significant differences among areas in levels of beryllium in 1998, the mean separation tests were not able to detect differences among pairs of areas ($\alpha = 0.05$). There was no significant evidence of elevated levels of metals in animals from the lagoon area, although there was a trend toward higher concentrations of lead at TA-53 for some individuals.

Table 7. Number of animals with detectable values[a] (n) and mean values (µg/g) with standard deviations (in parentheses) of metals found in hair of animals captured in 1997 and 1998 at Technical Area 53.

	Rock Squirrel				Raccoon				Striped Skunk				Grey Fox		Bobcat	
	1997 (14)[b]		1998 (18)		1997 (2)		1998 (1)		1997 (1)		1998 (1)		1996 (1)		1998 (1)	
Metal	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
Al	14	195 (59.6)	18	344 (176)	2	310 (49.5)	1	340	1	690	1	370	1	280	1	170
Sb	2	0.19 (0.08)	14	0.06 (0.05)	2	0.8 (0.7)	1	0.34	0	0.15	1	0.04	0	0.15	1	0.05
As	5	0.16 (0.12)	0	0.2 (0)	1	0.15 (0.07)	0	0.2	1	0.3	0	0.2	0	0.10	0	0.2
Ba	14	12.3 (8.3)	18	13.4 (6.1)	2	8.8 (3.2)	1	14.0	1	15.0	1	9.5	1	4.8	1	15
Be	0	0.035 (0)	3	0.04 (0.02)	0	0.035 (0)	0	0.035	1	0.094	0	0.035	0	0.035	0	0.035
Cd	3	0.65 (0.40)	0	0.45 (0)	1	1.23 (1.10)	1	1.3	0	0.45	0	0.45	0	0.45	0	0.45
Cr	2	0.73 (0.81)	2	0.55 (0.30)	2	3.35 (0.35)	1	1.6	1	1.3	0	0.45	0	0.45	0	0.45
Cu	14	19.5 (18.1)	17	8.4 (2.3)	2	20.5 (10.6)	1	12.0	1	11.0	1	6.1	1	9.9	1	9.7
Pb	14	6.1 (7.4)	18	2.8 (2.0)	2	7.7 (5.6)	1	14.0	1	4.6	1	2.1	1	2.0	1	1.3
Hg	0	0.25 (0)	2	0.18 (0.11)	0	0.25 (0)	0	0.15	1	0.5	1	0.5	1	0.7	0	0.15
Ni	0	2.0 (0)	1	2.1 (0.5)	0	2.0 (0)	0	2.0	0	2.0	0	2.0	0	2.0	0	2.0
Se	13	0.71 (0.24)	18	1.07 (0.29)	2	1.95 (0.35)	1	2.0	1	1.2	1	1.0	1	0.8	1	1.0
Ag	1	1.09 (0.35)	2	1.13 (0.38)	0	1.0 (0)	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0
Tl	0	0.15 (0)	18	0.02 (0.01)	0	0.15 (0)	1	0.066	0	0.15	0	0.017	0	0.15	1	0.01

[a] Detection limits were: Ag, 2.0; Al, 7.0; Be, 0.07; Cd, 0.9; Cr, 0.9; Cu, 1.0; Ni, 4.0; Pb, 0.3; Sb, 0.3 or 0.6 (1997) or 0.4 (1998); Tl, 0.3; Hg, 0.5 or 0.3; As, 0.2 (1997) or 0.4 (1998); Se, 0.3. For metals with more than one detection limit in a year the detection limit varied by submission group.

[b] The number in parentheses next to the year is the total number of animals that were sampled.

Table 8. Number of rock squirrels with detectable values [a] (n) and mean values with standard deviations (in parentheses) of metals (µg/g) found in hair for three areas at or near Los Alamos National Laboratory in 1997 and 1998. Superscript letters denote mean values that are significantly different from one another.

	At Lagoon				Away from Lagoon				Control Area					
	1997 (10) [b]		1998 (15)		1997 (4)		1998 (3)		1997 (5)		1998 (6)		1997	1998
Metal	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	P	P
Al	10	183 (45)^{A}	15	353 (191)	4	225 (87)^{AB}	3	303 (58)	5	692 (411)^{B}	6	405 (148)	**0.009**	0.539
Sb	1	0.18 (0.06)	12	0.07 (0.05)	1	0.21 (0.13)	2	0.05 (0.03)	0	0.27 (0.07)	4	0.05 (0.03)	0.116	0.589
As	4	0.18 (0.13)	0	0.2 (0)	1	0.13 (0.05)	0	0.2 (0)	5	1.2 (2.2)	3	0.3 (0.30)	0.085	1.0
Ba	10	9.4 (5.4)	15	12.7 (6.0)	4	19.6 (10.4)	3	16.7 (6.7)	5	16.9 (8.7)	6	16.3 (3.9)	0.089	0.085
Be	0	0.035 (0)^{A}	1	0.04 (0.01)	0	0.035 (0)^{A}	2	0.06 (0.03)	4	0.11 (0.05)^{B}	3	0.065 (0.036)	**0.001**	**0.049**
Cd	2	0.65 (0.42)	0	0.45 (0)	1	0.64 (0.38)	0	0.45 (0)	0	0.45 (0)	0	0.45 (0)	0.549	1.0
Cr	2	0.84 (0.95)	2	0.57 (0.33)	0	0.45 (0)	0	0.45 (0)	1	0.60 (0.34)	0	0.45 (0)	0.633	0.535
Cu	10	22.7 (20.7)	14	8.4 (2.3)	4	11.5 (2.6)	3	8.3 (2.4)	5	11.6 (2.6)	6	8.5 (1.4)	0.559	0.861
Pb	9	7.7 (8.3)	15	3.0 (2.2)	4	2.2 (1.9)	3	2.1 (0.8)	5	2.0 (0.9)	6	1.1 (0.3)	0.508	0.072
Hg	0	0.25 (0)	1	0.18 (0.12)	0	0.25 (0)	1	0.2 (0.09)	0	0.25 (0)	0	0.15 (0)	1.0	0.266
Ni	0	2.0 (0)	1	2.15 (0.57)	0	2.0 (0)	0	2.0 (0)	1	3.34 (3.0)	0	2.0 (0)	0.247	0.741
Se	9	0.6 (0.19)^{A}	15	1.09 (0.29)	4	0.95 (0.13)^{B}	3	1.0 (0.3)	3	0.73 (0.31)^{AB}	6	0.72 (0.39)	**0.028**	0.131
Ag	1	1.13 (0.41)	2	1.15 (0.41)	0	1.0 (0)	0	1.0 (0)	0	1.0 (0)	0	1.0 (0)	0.638	0.535
Tl	0	0.15 (0)	15	0.02 (0.01	0	0.15 (0)	3	0.03 (0 .01)	1	0.12 (0.06)	6	0.024 (0.005)	0.247	0.337

[a] Detection limits were: Ag, 2.0; Al, 7.0; Be, 0.07; Cd, 0.9; Cr, 0.9; Cu, 1.0; Ni, 4.0; Pb, 0.3; Sb, 0.3 or 0.6 (1997) or 0.04 (1998); Tl, 0.3; Hg, 0.5 or 0.3; As, 0.2 (1997) or 0.4 (1998); Se, 0.3. For metals with more than one detection limit in a year the detection limit varied by submission.

[b] The number in parentheses next to the year is the total number of animals that were sampled.

DISCUSSION

Effectiveness of the RFID Monitor and Trailmaster® Systems

We were pleased with the performance of the RFID tags. During this study and subsequent trapping at TA-53, we had six individuals trapped or detected in two consecutive years and an additional individual that was trapped in three consecutive years (L. Hansen, unpub. data). Once the wound caused by the syringe heals, the tags appear to remain in the animal, and we did not detect any long-term negative effects of this marking technique.

The RFID monitor and tags appeared to be effective at documenting the passages of marked animals into the lagoon. However, we were surprised at the low number of marked animals visiting the lagoon relative to the number of animals that were marked in the lagoon area. Only 4 of 10 marked animals in 1997 and 3 of 18 marked animals in 1998 were documented as using the lagoon.

The low rate of photographing marked animals was disappointing and suggested that while use of the Trailmaster® cameras may provide an indication of the relative numbers of each species using the lagoon, the photographs cannot be used as an indication of the total number of visits. It is recommended that a very regimented schedule for maintenance of the Trailmaster® detectors and cameras be used in future studies. Recommended maintenance includes checking the equipment at least once a week, replacing camera batteries every two weeks, replacing Trailmaster® detector batteries once a month, using longer roles of film, and being very careful to regularly clear the ground of all vegetation around the detectors.

Contaminant Levels

Radionuclides.-All species captured in the lagoon area except for striped skunk appeared to have at least some individuals with elevated concentrations of tritium in their urine. Rock squirrels captured around the lagoon had tritium concentrations significantly higher than the control population. The difference in tritium concentrations between female and male rock squirrels and the trend toward a correlation between tritium in the urine and distance from the lagoon for females, but not for males, suggest that differences in movement patterns between the sexes may be affecting their uptake of tritium. Ortega (1990) found that male rock squirrels have larger home ranges than females during May and June. Although the difference was not statistically significant, the mean distance traveled between trap locations was 165 m for males and 66 m for females during this study, also suggesting that males may have larger ranges than females. We observed at TA-53 that females had higher concentrations of tritium than males around the lagoon area, but males had higher concentrations away from the lagoon. This observation is consistent with females being more localized in their movements and hence having their tissue concentrations be more closely related to their proximity to the tritium source than males.

Two rock squirrels were collected from the lagoon area, and radionuclide concentrations in muscle and bone tissues were compared to concentrations from rock squirrels at LANL perimeter and regional background locations. Some radionuclides in rock squirrels that were collected from LANL TA-53 were higher than similar tissues from squirrels collected from background locations. Generally, the radionuclide concentrations in muscle and bone tissues were low. The doses estimated from the ingestion of muscle and bone from LANL animals, and especially from animals from perimeter locations—which were in the fraction of a mrem range—suggest that there are no significant health impacts to people that ingest these small game animals within and around the vicinity of TA-53 operations.

Metals.- Toxicity from metals occurs in critical organs, frequently the liver, kidney, or brain. For most metals, there is often not a close correlation between metals in hair and metals in critical organs. Therefore, the analysis of hair samples for metal concentrations is primarily useful as a screening tool. Both aluminum and barium occur naturally at relatively high concentrations in soils of Los Alamos County (Ferenbaugh et al. 1990). Ranges of selenium observed in this study were similar to those observed in a control population of raccoons (0.47–1.7 μg/g) that were used in a study in California (Clark et al. 1989). This suggests that these study animals were not exposed to excessive levels of selenium.

None of the metals tested had statistically higher levels at TA-53 than in our control location. However, the data suggest that lead might be elevated in some individuals in the lagoon area. Lead in hair has frequently been used as an indicator of exposure, and a safety limit of 9 μg/g in hair has been proposed for children (Revich 1994). In 1997, four rock squirrels from the lagoon area exceeded 9 μg/g lead in hair samples, with one rock squirrel having >25 μg/g. In 1998, although no rock squirrels had hair lead levels above 9 μg/g, concentrations in the lagoon area tended to be higher than away from the lagoon or in the control area (Kruskal-Wallis Test; $P = 0.072$). Two of the three raccoons caught at TA-53 in 1997 and 1998 exceeded 9 μg/g lead in hair samples. Water that exceeds TA-53 standards for metals is not released into the radioactive liquid waste lagoon. However, there are two old sewage lagoon basins adjacent to the liquid waste lagoon that may have elevated levels of metals in the soil, and lead may be associated with the industrial facilities, scrap metal, and older buildings on site.

<u>Relationship Between Time Spent at the PRS and Contaminant Levels</u>

There was no evidence at TA-53 that rock squirrels detected using the lagoon had higher levels of tritium than rock squirrels that were not observed using the lagoon. This result along with the observation that most rock squirrels from the lagoon area had elevated levels of tritium despite the fact that a relatively low proportion of them were detected at the lagoon suggests that indirect routes may be important pathways of tritium uptake for rock squirrels. Haarmann (1998) found that floral samples taken from near the lagoon in 1995 had tritium levels ranging from 1900 pCi/L to 405000 pCi/L, a range of concentrations similar to what we observed in rock squirrel urine from the lagoon area

(Figure 5). Breathing aerosolized tritium and consuming contaminated vegetation and/or soil are possible indirect routes of tritium uptake for rock squirrels.

We did not detect any gross signs of individual illness or population-level effects in animals from the lagoon area. Of the eight rock squirrels captured and released at the lagoon area in 1997, five were recaptured in 1998, indicating a minimum 62.5% annual survival rate for rock squirrels in the lagoon area during the study period. However, this study was not designed to examine population or individual health parameters of animals.

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Appendix 1. Tritium concentrations (pCi/L) and their associated counting uncertainties in urine samples collected from captured animals during 1997 and 1998.

Year/Identification	Sex	Date	Location	Tritium (pCi/L)	Uncertainity
1997					
Raccoon					
RA415B2B2B2F	F	6/26/97	away	3150	900
Rock Squirrel					
RS41592F2960	F	5/16/97	away	1720	820
RS4159240947	M	6/6/97	away	590	760
RS415935472E	M	6/6/97	away	6100	1000
RS415B202D25	M	5/13/97	away	8900	1200
RS3471	F	8/29/97	control	10	720
RS3475	F	8/1/97	control	840	770
RS8456	F	7/24/97	control	960	780
RS3457	F	8/13/97	control	330	740
RS4159260352	F	5/1/97	lagoon	6500	1100
RS4159434448	F	5/1/97	lagoon	1700	820
RS415B2E0E0D	F	5/15/97	lagoon	3520	920
RS415B2E0E0D	F	7/2/97	lagoon	2150	840
RS41593D4074	M	4/23/97	lagoon	2290	850
RS41593D4074	M	6/19/97	lagoon	3060	890
RS415B16361A	M	4/29/97	lagoon	4480	970
RS415B1C3313	M	4/29/97	lagoon	2300	850
RS415B226C18	M	4/30/97	lagoon	11600	1300
Striped Skunk					
S415B1A1E04	M	6/11/97	lagoon	10	720
1998					
Raccoon					
RA415B764800	M	5/28/98	away	1081000	31000
Rock Squirrel					
RS415C113127	F	5/19/98	away	220	710
RS415B202D25	M	3/11/98	away	280	710
RS27/26	F	7/6/98	control	-500	720
RS44/43	F	7/8/98	control	1550	840
RS51/52	F	6/16/98	control	470	770
RS92/91	F	7/13/98	control	-90	740
RS006/0001	M	6/15/98	control	190	760
RS22/18	M	6/9/98	control	240	760
RS46/45	M	7/8/98	control	-590	710
RS68/67	M	6/10/98	control	-600	710
RS69/70	M	6/10/98	control	-210	730
RS76/77	M	6/24/98	control	340	770
RS8/7	M	6/18/98	control	-230	730
RS96/97	M	6/23/98	control	540	780
RS93/94	M	7/9/98	control	-20	740
RS4157781726	F	5/21/98	lagoon	25600	1800
RS415816517E	F	4/13/98	lagoon	27800	1900

Year/Identification	Sex	Date	Location	Tritium (pCi/L)	Uncertainity
RS415822644D	F	3/25/98	lagoon	2890	860
RS4159260352	F	4/23/98	lagoon	42200	2400
RS4159260352	F	5/20/98	lagoon	12100	1300
RS4159434448	F	4/3/98	lagoon	1710	800
RS4159434448	F	4/13/98	lagoon	920	750
RS415A3C2C55	F	5/8/98	lagoon	530	730
RS415A556271	F	4/22/98	lagoon	11200	1300
RS415B2B791C	F	4/24/98	lagoon	14400	1400
RS415B35675A	F	4/22/98	lagoon	14200	1400
RS415B35675A	F	5/11/98	lagoon	10000	1200
RS415B76720F	F	5/21/98	lagoon	25800	1800
RS415806073B	M	5/27/98	lagoon	1140	760
RS4158514C61	M	4/16/98	lagoon	1370	780
RS41593D4074	M	5/20/98	lagoon	1680	800
RS415B1C3313	M	4/30/98	lagoon	4490	950
RS415B7E3853	M	5/21/98	lagoon	1200	770
Striped Skunk					
S415B1A1E04	M	3/11/98	lagoon	20	690

Appendix 2a. Concentrations of Ag, Al, Ba, Be, Cd, Cr, and Cu (µg/g) and their associated uncertainties (U) in hair samples from medium-sized mammals captured in 1997 and 1998. Values without uncertainties were below the detection limit and are listed as ½ of the detection limit.

Year/Identification	Sex	Date	Location	Ag		Al		Ba		Be		Cd		Cr		Cu	
				µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U
1996																	
Grey Fox																	
F150	F	12/13/96	lagoon	1.0		280	28	4.8	0.48	0.035		0.45		0.45		9.9	1
1997																	
Raccoon																	
RA415B2B2B2F	F	6/26/97	away	1.0		310	31	11	1.1	0.035		2	0.9	3.6	0.9	28	2.8
RA415B195A14	M	3/18/97	lagoon	1.0		380	3.8	6.5	0.65	0.035		0.45		3.1	0.9	13	1.3
Rock Squirrel																	
RS41592F2960	F	5/16/97	away	1.0		160	16	7.5	0.75	0.035		0.45		0.45		10	1
RS4159240947	M	6/4/97	away	1.0		220	22	31	3.1	0.035		0.45		0.45		9.1	1
RS415935472E	M	6/6/97	away	1.0		350	35	25	2.5	0.035		1.2	0.9	0.45		15	1.5
RS415B202D25	M	5/13/97	away	1.0		170	17	15	1.5	0.035		0.45		0.45		12	1.2
RS3471	F	8/29/97	control	1.0		230	23	5.9	0.59	0.035		0.45		0.45		12	1.2
RS3473	F	8/12/97	control	1.0		1000	100	26	2.6	0.099	0.07	0.45		0.45		8.6	1
RS3475	F	8/1/97	control	1.0		670	67	23	2.3	0.16	0.07	0.45		1.2	0.9	13	1.3
RS8456	F	7/24/97	control	1.0		360	36	9.7	0.97	0.14	0.07	0.45		0.45		15	1.5
RS3457	F	8/13/97	control	1.0		1200	120	20	2	0.097	0.07	0.45		0.45		9.4	1
RS4159260352	F	5/1/97	lagoon	1.0		260	26	17	1.7	0.035		1.4	0.9	1.4	0.9	62	6.2
RS4159434448	F	5/1/97	lagoon	2.3	2	200	20	10	1	0.035		0.45		0.45		11	1.1
RS415B2E0E0D	F	5/15/97	lagoon	1.0		150	15	7.3	0.73	0.035		0.45		0.45		11	1.1
RS415B35675A	F	3/28/97	lagoon	1.0		120	12	5	0.5	0.035		0.45		0.45		26	2.6
RS9	F	5/30/97	lagoon	1.0		150	15	21	2.1	0.035		0.45		0.45		13	1.3
RS1	M	7/2/97	lagoon	1.0		230	23	7.4	0.74	0.035		0.45		0.45		9.3	1
RS41593D4074	M	3/28/97	lagoon	1.0		190	19	7.7	0.77	0.035		0.45		0.45		13	1.3
RS415B16361A	M	4/9/97	lagoon	1.0		130	13	4.1	0.41	0.035		0.45		0.45		11	1.1
RS415B1C3313	M	3/19/97	lagoon	1.0		210	21	5.9	0.59	0.035		0.45		0.45		11	1.1

Year/Identification	Sex	Date	Location	Ag		Al		Ba		Be		Cd		Cr		Cu	
				µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U
RS415B226C18	M	4/30/97	lagoon	1.0		190	19	8.5	0.85	0.035		1.5	0.9	3.4	1.43	60	6
Striped Skunk																	
S415B1A1E04	M	6/11/97	lagoon	1.0		690	69	15	1.5	0.094	0.07	0.45		1.3	0.9	11	1.1
1998																	
Bobcat																	
B415B521674	F	3/4/98	away	1.0		170	17	15	1.5	0.035		0.45		0.45		9.7	1
Raccoon																	
RA415B764800	M	5/28/98	away	1.0		340	34	14	1.4	0.035		1.3	0.9	1.6	0.9	12	1.2
Rock Squirrel																	
RS41583E0C46	F	3/24/98	away	1.0		370	37	19	1.9	0.035		0.45		0.45		11	1.1
RS415C113127	F	5/19/98	away	1.0		270	27	22	2.2	0.077	0.07	0.45		0.45		7	1
RS415B202D25	M	3/11/98	away	1.0		270	27	9.2	0.92	0.079	0.07	0.45		0.45		6.8	1
RS51/52	F	6/16/98	control	1.0		390	39	20	2	0.077	0.07	0.45		0.45		5.9	1
RS006/0001	M	6/15/98	control	1.0		360	36	17	1.7	0.035		0.45		0.45		9.1	1
RS22/18	M	6/9/98	control	1.0		440	44	20	2	0.087	0.07	0.45		0.45		9.2	1
RS68/67	M	6/10/98	control	1.0		280	28	11	1.1	0.035		0.45		0.45		8.3	1
RS69/70	M	6/10/98	control	1.0		280	28	12	1.2	0.035		0.45		0.45		8.7	1
RS8/7	M	6/18/98	control	1.0		680	68	18	1.8	0.12	0.07	0.45		0.45		10	1
RS4157781726	F	5/21/98	lagoon	1.0		180	18	10	1	0.035		0.45		0.45		8.9	1
RS415816517E	F	4/13/98	lagoon	1.0		420	42	14	1.4	0.035		0.45		0.45		12	1.2
RS415822644D	F	3/25/98	lagoon	1.0		460	46	32	3.2	0.086	0.07	0.45		1.6	0.9	8.1	1
RS4159260352	F	4/23/98	lagoon	1.0		280	28	8.8	0.88	0.035		0.45		0.45		9.5	1
RS4159434448	F	4/3/98	lagoon	1.0		390	39	10	1	0.035		0.45		0.45		6.6	1
RS415A3C2C55	F	5/8/98	lagoon	1.0		530	53	17	1.7	0.035		0.45		0.45		9.9	1
RS415A556271	F	4/22/98	lagoon	1.0		480	48	11	1.1	0.035		0.45		0.45		7	1
RS415B2B791C	F	4/24/98	lagoon	1.0		840	84	14	1.4					1.1	0.9	7.4	
RS415B35675A	F	4/22/98	lagoon	1.0		480	48	7.4	0.74	0.035		0.45		0.45		14	1.4
RS415B76720F	F	5/21/98	lagoon	2	2	150	15	15	1.5	0.035		0.45		0.45		6.4	1
RS415806073B	M	5/27/98	lagoon	1.0		200	20	11	1.1	0.035		0.45		0.45		7.8	1

Year/Identification	Sex	Date	Location	Ag		Al		Ba		Be		Cd		Cr		Cu	
				µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U
RS41593D4074	M	5/20/98	lagoon	1.0		170	17	9.7	0.97	0.035		0.45		0.45		6.4	1
RS415B0A6D7B	M	3/23/98	lagoon	1.0		140	16	8.7	1.168	0.035		0.45		0.45		6.3	1
RS415B1C3313	M	4/30/98	lagoon	1.0		340	34	8.8	0.88	0.035		0.45		0.45		9.5	1
RS415B7E3853	M	5/21/98	lagoon	2.3	2	230	23	13	1.3	0.035		0.45		0.45		5.7	1
Striped Skunk																	
S415B1A1E04	M	3/11/98	lagoon	1.0		370	37	9.5	0.95	0.035		0.45		0.45		6.1	1

Appendix 2b. Concentrations of Ni, Pb, Sb, Tl, As, Se, and Hg (µg/g) and their associated uncertainties (U) in hair samples from medium-sized mammals captured in 1997 and 1998. Values without uncertainties were below the detection limit and are listed as ½ of the detection limit.

Year/Identification	Sex	Date	Location	Ni		Pb		Sb		Tl		As		Se		Hg	
				µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U
1996																	
Grey Fox																	
F150	F	12/13/96	lagoon	2		2	0.7	0.15		0.15		0.1		0.8	0.3	0.7	0.5
1997																	
Raccoon																	
RA415B2B2B2F	F	6/26/97	away	2		11.6	0.4	1.3	0.3	0.15		0.2	0.2	1.7	0.3	0.25	
RA415B195A14	M	3/18/97	lagoon	2		3.7	0.3	0.3	0.3	0.15		0.1		2.2	0.3	0.25	
Rock Squirrel																	
RS41592F2960	F	5/16/97	away	2		0.6	0.3	0.15		0.15		0.1		0.9	0.3	0.25	
RS4159240947	M	6/4/97	away	2		1.6	0.3	0.15		0.15		0.1		1.1	0.3	0.25	
RS415935472E	M	6/6/97	away	2		4.9	0.3	0.4	0.3	0.15		0.2	0.2	1	0.3	0.25	
RS415B202D25	M	5/13/97	away	2		1.8	0.3	0.15		0.15		0.1		0.8	0.4	0.25	
RS3471	F	8/29/97	control	2		1	0.3	0.15		0.012	0.003	5.2	1	0.8	0.2	0.25	
RS3473	F	8/12/97	control	2		2.9	0.3	0.3		0.15		0.2	0.2			0.25	
RS3475	F	8/1/97	control	8.7	4	1.9	0.4	0.3		0.15		0.2	0.2			0.25	
RS8456	F	7/24/97	control	2		1.4	0.3	0.3		0.15		0.2	0.2	1	0.3	0.25	

Year/Identification	Sex	Date	Location	Ni		Pb		Sb		Tl		As		Se		Hg	
				µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U
RS3457	F	8/13/97	control	2		3	0.3	0.3		0.15		0.2	0.2	0.4	0.3	0.25	
RS4159260352	F	5/1/97	lagoon	2		25.9	0.6	0.15		0.15		0.5	0.2	0.3	0.3	0.25	
RS4159434448	F	5/1/97	lagoon	2		11.4	0.3	0.15		0.15		0.2	0.2	0.6	1	0.25	
RS415B2E0E0D	F	5/15/97	lagoon	2		14.6	0.4	0.15		0.15		0.3	0.2	0.3	0.3	0.25	
RS415B35675A	F	3/28/97	lagoon	2		1.5	0.3	0.15		0.15		0.1		0.7	0.3	0.25	
RS9	F	5/30/97	lagoon	2		1.3	0.3	0.15		0.15		0.1		0.8	0.3	0.25	
RS1	M	7/2/97	lagoon	2		2.8	0.3	0.3		0.15		0.2	0.2			0.25	
RS41593D4074	M	3/28/97	lagoon	2		12.3	0.3	0.3	0.3	0.15		0.1		0.8	0.3	0.25	
RS415B16361A	M	4/9/97	lagoon	2		1	0.3	0.15		0.15		0.1		0.7	0.3	0.25	
RS415B1C3313	M	3/19/97	lagoon	2		1	0.3	0.15		0.15		0.1		0.6	0.3	0.25	
RS415B226C18	M	4/30/97	lagoon	2		5		0.15		0.15		0.1		0.6	0.3	0.25	
Striped Skunk																	
S415B1A1E04	M	6/11/97	lagoon	2		4.6	0.3	0.15		0.15		0.3	0.2	1.2	0.3	0.5	0.5
1998																	
Bobcat																	
B415B521674	F	3/4/98	away	2		1.3	0.3	0.05	0.04	0.01	0.003	0.2		1	0.2	0.15	
Raccoon																	
RA415B764800	M	5/28/98	away	2		14	0.6	0.34	0.04	0.066	0.004	0.2		2	0.6	0.15	
Rock Squirrel																	
RS41583E0C46	F	3/24/98	away	2		2.5	0.4	0.07	0.04	0.033	0.004	0.2		0.7	0.2	0.3	0.3
RS415C113127	F	5/19/98	away	2		2.5	0.3	0.05	0.04	0.018	0.003	0.2		1.3	0.4	0.15	
RS415B202D25	M	3/11/98	away	2		1.2	0.3	0.02		0.026	0.003	0.2		1	0.2	0.15	
RS51/52	F	6/16/98	control	2		0.9	0.3	0.02		0.019	0.003	0.2		0.5	0.2	0.15	
RS006/0001	M	6/15/98	control	2		0.9	0.3	0.05	0.04	0.025	0.003	0.2		1.1	0.2	0.15	
RS22/18	M	6/9/98	control	2		1.1	0.3	0.1	0.06	0.03	0.01	0.2	0.2	0.8	0.2	0.15	
RS68/67	M	6/10/98	control	2		0.7	0.3	0.02		0.018	0.003	0.2	0.2	0.2	0.2	0.15	
RS69/70	M	6/10/98	control	2		1.3	0.3	0.05	0.04	0.027	0.003	0.1		0.5	0.2	0.15	
RS8/7	M	6/18/98	control	2		1.6	0.3	0.04	0.04	0.024	0.003	0.9	1.5	1.2	0.2	0.15	
RS4157781726	F	5/21/98	lagoon	2		0.8	0.3	0.02		0.012	0.003	0.2		1.2	0.4	0.15	
RS415816517E	F	4/13/98	lagoon	2		1	0.3	0.02		0.013	0.003	0.2		0.9	0.4	0.15	

Year/Identification	Sex	Date	Location	Ni		Pb		Sb		Tl		As		Se		Hg	
				µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U	µg/g	U
RS415822644D	F	3/25/98	lagoon	2		2.7	0.3	0.22	0.07	0.033	0.003	0.2		1.4	0.4	0.15	
RS4159260352	F	4/23/98	lagoon	2		0.6	0.3	0.12	0.05	0.02	0.01	0.2		1.4	0.4	0.15	
RS4159434448	F	4/3/98	lagoon	2		2.6	0.3	0.05	0.04	0.021	0.004	0.2		1.6	0.6	0.6	0.3
RS415A3C2C55	F	5/8/98	lagoon	2		8.7	0.3	0.11	0.04	0.018	0.003	0.2		0.6	0.4	0.15	
RS415A556271	F	4/22/98	lagoon	2		1.4	0.3	0.04	0.04	0.019	0.003	0.2		0.9	0.4	0.15	
RS415B2B791C	F	4/24/98	lagoon	2		3.6	0.3	0.06	0.04	0.022	0.003	0.2		0.7	0.4	0.15	
RS415B35675A	F	4/22/98	lagoon	2		4.6	0.3	0.06	0.04	0.024	0.003	0.2		0.9	0.8	0.15	
RS415B76720F	F	5/21/98	lagoon	2		1.3	0.3	0.05	0.04	0.015	0.003	0.2		1.2	0.4	0.15	
RS415806073B	M	5/27/98	lagoon	2		4.2	0.3	0.06	0.04	0.027	0.003	0.2		0.8	0.4	0.15	
RS41593D4074	M	5/20/98	lagoon	2		3.3	0.3	0.04	0.04	0.059	0.003	0.2		1.1	0.4	0.15	
RS415B0A6D7B	M	3/23/98	lagoon	2		1.2	0.3	0.02		0.012	0.003	0.2		1	0.4	0.15	
RS415B1C3313	M	4/30/98	lagoon	4.2	4	5.3	0.3	0.05	0.04	0.014	0.003	0.2		1.4	0.4	0.15	
RS415B7E3853	M	5/21/98	lagoon	2		3.3	0.3	0.07	0.04	0.022	0.003	0.2		1.2	0.4	0.15	
Striped Skunk																	
S415B1A1E04	M	3/11/98	lagoon	2		2.1	0.3	0.04	0.04	0.017	0.003	0.2		1	0.2	0.5	0.3

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